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- R. XXVI. *Account of a new Kind of inflammable Air or Gase, which can be made in a Moment without Apparatus, and is as fit for Explosion as other inflammable Gasses in use for that Purpose; together with a new Theory of Gunpowder. By John Ingen-Houfz, Body Physician to their Imperial Majesties, and F. R. S.*

Read March 25, 1779.

THE important discoveries on different kinds of air have opened a new field for one of the most pleasing and interesting scenes which ever were exposed to the contemplation of philosophers, and therefore could not fail of exciting in almost every lover of natural knowledge a decided curiosity to see the pursuit of such striking novelties, and in many an almost irresistible temptation to imitate them, and to pursue farther the road already so far opened by the Rev. Dr. PRIESTLEY, Abbe FONTANA, Mr. LAVOISIER, and many other learned and ingenious men.

Who can, indeed, without the greatest satisfaction, look (amidst many other objects of admiration) upon the
discovery

discovery of that new aerial fluid, which in purity and fitness for respiration so far surpasses the best atmospheric air, that an animal protracts his life five times as long, or even more, in it than in common air of the best quality?

Dr. PRIESTLEY, the first who discovered this wonderful fluid, extracted it from bodies which we should rather have suspected to have contained deleterious exhalations. He afterwards found it existed in many other bodies in which the most accurate observer never found any thing of an approaching nature.

When I consider the immense quantity of this pure aerial fluid, called by Dr. PRIESTLEY with so much propriety *dephlogisticated air*, which exists as it were in a solid state in nitre, in calcined metals, and even in some other of the most common substances, I cannot express the greatness of my expectation, as a physician, from such an important discovery ^(a). I flatter myself, that ere long an easy and cheap method will be discovered by which such quantities of this beneficial air may be ob-

(a) Since Dr. PRIESTLEY's last publication on air, he discovered, that the same water which, if examined immediately, gives only a small quantity of bad air, yields spontaneously about ten times the quantity of pure dephlogisticated air after standing some time exposed to the sun. Of this I was an eye-witness. The important discoveries of Abbé FONTANA upon this subject, which he shewed me when I was last in Paris a year and a half ago, will soon be published by himself. He extracted this wonderful aerial fluid from different kinds of water by boiling them over a fire.

tained as will serve to cure several diseases which resist the power of all other remedies, and so prolong, as it were, human life. We may expect, with some degree of confidence, that this new element, when it shall be used for the benefit of respiration, will be found more fit than the best common air to free our body from that quantity of phlogiston or inflammable principle which seems to exist sometimes in too great a quantity in the mass of our blood; or from which it seems sometimes, as it were, to be let loose in too great abundance, producing, perhaps, in consequence fevers and other symptoms, the causes of which have not yet been clearly elucidated by the best medical writers.

This dephlogisticated air, free from the inflammable particles with which the best common air is always infected, will probably be found capable of absorbing a greater quantity of those phlogistic particles with which the air coming from our lungs is always found to be pregnant, and thus of ventilating, as it were, much more expeditiously the mass of our blood of that which a constant exertion of the organs of respiration is not always able to free it from in a sufficient quantity.

These important pursuits have led Dr. PRIESTLEY to the discovery of one of the benefits, and perhaps the principal, we derive from respiration; that function of the

animal oeconomy which is so important, that without its constant influence an animal, once born, has but a few moments to live.

The criterion of the degree of goodness of respirable air, by the quantity which is absorbed or destroyed by the addition of nitrous air, is one of those useful discoveries of Dr. PRIESTLEY's from which mankind will, perhaps, hereafter reap a considerable benefit.

The discovery of the various kinds of inflammable airs or gasses becoming powerfully explosive, when they are mixed with a sufficient quantity of common air, and still more so when they are combined with dephlogisticated air, is one of those improvements in natural philosophy which, giving occasion to various amusing and interesting experiments, have cast at the same time a new light upon some powerful agents, whose mischievous force was known, though their nature was still in the dark.

As those inflammable airs have been of late years one of the principal philosophical amusements, I intend to lay before the Royal Society an easy method of producing, without any trouble or particular apparatus, such quantity of an inflammable air or gas as may be required; to which I shall subjoin some considerations which have occurred to me about the nature of that wonderful substance gunpowder, which conveys death at such an immense distance by its almost irresistible explosive force,

force, by which it propels metallic balls of a considerable weight. To investigate the nature of this awful ingredient, by which the fate of empires is decided in our days, cannot be indifferent to any body who takes delight in investigating natural causes.

Being at Amsterdam in November 1777, Messieurs AENEAE and CUTHBERTSON, two ingenious philosophers of that city, were so good as to shew me some curious experiments with explosive and inflammable airs of different kinds. They produced an inflammable air, by mixing together equal quantities of oil of vitriol and spirit of wine, and applying heat to the phial containing the compound. A great quantity of white vapour was extricated, which, passing up the inverted receiver filled with water, settled at the top and depressed the water, as other airs do. This air soon became clear, the white fumes being absorbed by the water. This air was easily lighted in an open cylindrical glass, and burnt almost as clear as a candle, the flame descending gradually lower and lower till it reached the bottom. A very little quantity of this air mixed with common or dephlogisticated air, for instance, one fourteenth or one tenth part, and kindled by an electrical spark, exploded with a very loud report, and shattered the glass to pieces in which it was kindled, when it did not find a ready vent.

They

They had contrived a kind of a pistol for the purpose, consisting of a strong cylindrical glass tube with a piston adapted to it. To the end of this tube was fixed a brass barrel, like that of a common pistol: into this barrel a brass bullet was put loose, so that the barrel was placed a little above the level, to prevent the bullet rolling out. The barrel was directed to a board of oak at eight or ten feet distance. A proper quantity of common and inflammable air (produced in the manner above mentioned) being drawn into the glass tube by means of the piston, it was fired by directing an electrical explosion through it. The explosion was very loud: the ball hit the board with such a force that it made a strong impression in it, and recoiled with a considerable force, so as to hit the wall behind us, and to put us in some danger of being hurt by its rebounding force.

The same gentlemen told me, that this inflammable air had in some respects the advantage over the inflammable airs extracted from metals by the vitriolic or marine acid, and that extracted from mud or marshes; because this air being heavier than either of these airs, and even than common air, is not so easily lost out of an open vessel; and, that when it escapes into the open air, it agreeably perfumes the room with the smell of *spiritus vitrioli dulcis* or æther; whereas the other inflammable airs,

which from their less specific gravity escape easily into the common air, yield an offensive, disagreeable stench.

Mr. AENEAE, having examined the specific gravities of the different inflammable airs compared with common air, favoured me with the following result of his inquiries.

A vessel, which contained the weight of 138 grains of common air, contained 25 grains of inflammable air extracted from iron by vitriolic acid, and 92 grains of inflammable air extracted from mud or marshes, and 150 grains of that extracted from oil of vitriol and spirit of wine.

I was much pleased with the above mentioned experiment, and immediately thought that the operation of extracting this inflammable air or vapour could be dispensed with by employing vitriolic æther, which in reality is contained in the vapour expelled by heat from oil of vitriol and spirit of wine, which vapour, condensed in the process of distillation, yields æther. But I resolved to defer making the experiment till I should arrive in London, where I intended to make some stay to see my old friends, and acquire what medical and philosophical knowledge I could.

Having arrived in this capital in the beginning of January 1778, I lost no time in pursuing my idea. For

this purpose I poured some drops of æther into a strong glass tube, and directed an electrical explosion from a Leyden phial through it; but, to my mortification, no explosion happened. I then threw a bit of cotton, dipped in æther, into the same tube, but it would not take fire. Though these first trials proved unsuccessful, I was too much persuaded, that in some way or other it must succeed, to be discouraged. I tried it in several different ways, and at last, before the end of January, I succeeded once or twice in producing a loud explosion, by throwing into the tube a little bit of paper dipped in æther. But as the experiment often failed (of which I could then find no reason), I did not venture to shew it to my friends till I had hit upon a method, the certainty of which would prevent my being exposed to some confusion by exhibiting an experiment which was so apt to fail. However, I told Sir JOHN PRINGLE, Mess. NAIRNE and BLUNT, and some few others of my friends, early in the spring, that I had found out a method of firing an inflammable air pistol without being at the trouble of making inflammable air in the ordinary way; as I produced it at pleasure in an instant, without any trouble or apparatus: and that I would shew them the experiment as soon as I was sure of succeeding constantly. In the mean time I continued to produce this air before my acquaintance in

the way I had seen it produced at Amsterdam. Soon after, hitting upon better and surer methods of succeeding, I began to show it to those who came to visit me, and in the beginning of the summer I made no scruple of shewing it to every body.

The reasons why I did not succeed in the beginning I found afterwards to be, either that I employed too great a quantity of æther, or that the air or vapour of the æther was not thoroughly incorporated with the other air; for the same numbr of drops of æther poured into the air pistol, which would not produce an explosion when the pistol was not shaken, made a very loud one when it was forcibly agitated.

The surest method of succeeding I find to be the following: I dip a small glass tube, open on both sides, and the bore of which is one twelfth of an inch in diameter into a phial containing æther, and when two or three drops of the liquid have entered the tube I apply my finger to the upper end of it, to keep the liquor suspended. I take the tube out of the phial, and thrust it immediately into a small *caoutchouc*, or elastic gum bottle: this being done, I withdraw my finger from the tube, and take it out of the *caoutchouc*; thus the little quantity of æther, suspended in the end of the tube, is dropped into the *caoutchouc*, the neck of which is to be
immediately

immediately inverted into the orifice of the air pistol, and, after giving it a gentle squeeze, withdrawn out of it: after which, a bullet or a cork is to be thrust into the mouth of the pistol, when it is ready for firing. This whole operation may be performed in the space of five or six seconds.

The considerable force of explosion, and the loud report of the ordinary inflammable airs, induced Mr. VOLTA, of Como, to believe, that these airs might, perhaps, become a substitute to gunpowder. If this expectation had been well founded, the greatest *desideratum* would, I think, have been to find out a way to produce such air at any time without trouble, and to carry it about in as little compass as possible: which two conditions I should have pretty nearly fulfilled; as all the inflammable air requisite for the explosion of the pistols contrived by Mr. VOLTA is contained in the bulk of one single drop of æther; which drop, poured in the pistol itself, is full sufficient to produce a very powerful explosion. But how far this expectation of Mr. VOLTA, as to the use of inflammable air in offensive arms, is well grounded, I will attempt to explain in the subsequent part of this paper.

This inflammable air (which, perhaps, might more properly be called vapour, as it is absorbable by water) has

has the principal properties of the other inflammable airs, *viz.* it will not inflame but where it is in contact with common or dephlogisticated air; and therefore only takes fire at the top of the vessel containing it, the flame going gradually downwards till the whole is consumed, if the vessel is of a cylindrical form, and pretty wide. If it is diluted with common air, but not sufficiently, it will burn as other inflammable air without exploding. Being sufficiently diluted with common air, especially with dephlogisticated air, it explodes with a very great report and a considerable force. It is unfit for respiration in a concentrated state, and is as mortal for an animal plunged into it as any other of the inflammable airs; though in a diluted state it seems to be rather pleasant to the organs of respiration.

It differs in some respects from the common inflammable airs; as, for instance, it is much heavier, as is already observed, than any of the other inflammable airs, and even than common air. It does not inflame or explode with so small a spark of electrical fire as the other inflammable airs, requiring the explosion of a Leyden phial to be fired with certainty, though one single inch of coated glass will be sufficient; so that a Leyden phial, containing twelve or fourteen square inches of coating, may fire an air pistol loaded with this kind of air several times,

times, if the charge be divided by taking it out with a small glass tube, fitted up in the manner I described in the paper I had the honour of laying before the Royal Society last year, and which is inserted in the second part of the 68th vol. of the Phil. Transf.; in which paper I describe a kind of an electrical match to light a candle with. This air being in contact with water is absorbed by it in a few days, though the water be not stirred: and much sooner loses its inflammability by contact with water than the other inflammable airs do. However, I found that in such a situation this air had not yet lost all its explosive force in six days, though the water in which the cylindrical glass, ten inches long and one in diameter, was inverted, after I had poured into it five or six drops of æther, had gradually ascended till, on the third day, it reached to the half of the height of the glass: so that it seems as if these drops of æther, by their expanding in the form of air, had forced out half of the common air contained in the glass, in the place of which the water afterwards ascended in proportion as the air or vapour generated by the æther was absorbed by the water.

That this air is specifically heavier than common air, and does not readily incorporate with it, is easily demonstrated by the following experiment. I poured five or six drops of æther into a cylindrical glass, ten inches long
and

and one inch in diameter: the æther being soon evaporated, I clapped my hand upon the mouth of the glass, and inverted it to incorporate the air generated by the æther with the common air; after which I left the glass open during half an hour, when I dipped in it a piece of wax taper burning, stuck upon a bended wire. As soon as the taper reached the brim of the glass, a flame burst out with a weak explosion. In a quarter of an hour I again thrust the wax taper into the same cylinder, and no flame was observed till the wax taper reached the place where the flame ended the first time. This second explosion did not set fire to the whole at the bottom of the glass. I again waited a quarter of an hour, and then again thrust the wax taper into it, by which the remainder of this inflammable gas, which had remained settled all that time at the bottom, was exploded ^(b).

(b) It is remarkable, that æther, the most volatile liquor yet known, and so apt to spread itself through the air by a quick evaporation that a drop of very fine æther, which falls from the height of a few feet, is quite evaporated before it reaches the ground, and no glass stopper of itself is able to keep it from evaporating: it is remarkable, I say, that notwithstanding this extreme volatility, the air or vapour, into which it changes by evaporation, should be so far from participating of the same volatility, that it may be kept hours together in an open cylindrical vessel without evaporating, mixing with the common air, or losing its inflammability; so that this substance seems to undergo a sudden metamorphosis, and to change in an instant from the lightest of all liquors to one of the heaviest of aerial fluids, fixed air, which being one half heavier than common air, according to the experiments of Mr. CAVENDISH, is probably much heavier than this æther air.

I found

I found that æther, in which as much urinous phosphorus is dissolved as will make it luminous in the dark, when some drops are poured upon water; is very brisk in taking fire, when employed for an inflammable air pistol; but that the experiment, when repeated, will be apt to fail, because the phosphoric acid which remains in the pistol, and by its nature attracts the humidity of the atmosphere, will soon fill the inside of the pistol with a coat of moisture, and prevent the electrical spark from kindling the inflammable air.

It appeared, that a little camphire dissolved in æther increases its explosive force, and makes it less apt to fail.

As this inflammable air is heavier than common air, it is clear, that the mouth of the air pistol should be kept upwards at the time of charging it: whereas it is better to invert the pistol when the ordinary inflammable airs are employed, which, being specifically lighter than common air, rise of themselves in the pistol when its mouth is placed inverted upon the orifice of the vessel which contains them.

It is true, that the squeezing the elastic gum bottle, when placed upon the pistol, forces some of the inflammable gas out of it, which is lost in the common air; but notwithstanding this waste, the inflammable air which

remains in the pistol is sufficient to produce a loud report, which is all that is required. Indeed, one single drop of the æther could be easily shaken out of the glass tube immediately into the pistol, without making use of the elastic gum bottle; but this drop, evaporating into elastic air, leaves behind it a good deal of moisture, whether inherent in the æther itself, or attracted from the atmosphere. This moisture, in the way I use to load the pistol, remains in the elastic gum bottle, which is therefore always found moist when the experiment is repeated several times.

It was, indeed, known before this time, that æther and other volatile inflammable liquors spread by evaporating inflammable effluvia through the surrounding air, especially when they are heated; and that these effluvia have sometimes by the imprudent approach of a candle taken fire, and conveyed the inflammation to the liquor itself: but I never heard that any body employed these liquors instead of ordinary inflammable air in communicating to common air an explosive quality, or in firing inflammable air pistols, before I communicated the experiment to my friends

As it will, I think, appear very probable, by what will be said hereafter, that little more than a pleasing amusement can be expected from the force of any inflammable
air;

air; the ready production of such inflammable air always ready for use, when an explosion is intended to be produced, may be of some importance to philosophers whose time must be sparingly taken up.

Comparative view of the expanding force of explosive air and gunpowder.

The force of gunpowder has been ascribed by Sir ISAAC NEWTON and all other philosophers to the sudden extrication of an amazing quantity of elastic permanent aerial fluid within a narrow space incapable of containing it; which quantity ought to be attentively attended to, in order to estimate the comparative power of the two substances.

BENJAMIN ROBINS, whose work, intituled, *New Principles of Gunnery*, passes in this country for a standard book, affirms, that gunpowder, when fired, generates a permanent elastic fluid of 250 times the bulk of the powder before it was fired. He found, that common air, which is heated by the contact of a red-hot iron, expands to four times its former bulk. Hence he concludes, that the elastic air, disengaged from gunpowder, must expand also to four times its dimension; and that it occupies about a thousand times the bulk of the powder in the moment of inflammation.

The learned Count SALUCE remarks ^(c), that the elastic air generated by the inflammation of gunpowder occupies, when cold, 222 times the bulk of the powder, which agrees, as he finds, with the computation made by Mess. HAUKEBEE, AMONTONS, and BELIDOR. This calculation he confirms in the *Melanges de Philosophie et des Mathematiques de la Societ  Royale de Turin*, which is a continuation of the former work. He is of opinion, that this elastic fluid is of the same nature with common air (which was likewise the opinion of Dr. HALES); and that the prodigious force of gunpowder depends upon the action of the fire on all its parts, by which this fluid exercises all the force of its elasticity.

The extrication of such a considerable quantity of a permanent elastic fluid by the firing of gunpowder has been put to a particular use by several philosophers.

The celebrated Mr. DE LA CONDAMINE gives an account of a brass air gun contrived by one Mr. MATY, of Turin; which he loaded with air condensed by firing in it two ounces of gunpowder, which, by its inflammation, let loose such a quantity of air as was sufficient to shoot a leaden bullet sixty paces, and to repeat the process

(b) *Miscellanea Philosophico-Mathematica Societatis privatae Taurinensis*, p. 125.

eighteen times, the strength of the explosion diminishing gradually as in other air guns ^(d).

In the learned work of Mr. ANTONI, an Italian gentleman, I find the same experiment, the account of which is accompanied with a figure of such an air gun, in which the author fired one ounce of gunpowder, the barrel being very stout, and of a size capable of containing ten ounces. He afterwards let a quantity of this compressed air out by a valve in the same way as it is done in the common air guns. This one ounce of gunpowder yielded air enough to propel a leaden bullet through a board three lines thick; at the distance of forty paces, and to repeat the process sixteen or eighteen times ^(e).

The difference of the quantity of elastic fluid obtained from the firing of gunpowder by Mr. ROBINS and others might be owing to the difficulties attending the investigation, or to the different proportion of the ingredients used in the composition of the powder; as it is well known, that gunpowder for the use of the army is made of five or six parts of nitre to one of charcoal,

(d) Extrait d'un Journal de Voyage d'Italie, par M. DE LA CONDAMINE, inséré dans les Mémoires de l'Académie Royale des Sciences de Paris, 1757, p. 405.

(e) Examen de la Poudre traduit de l'Italien de M. ANTONI, par M. le Vicomte de FLAVIGNY, 1773.

and one of sulphur; when seven parts of nitre are used, it is called *poudre d'artifice*.

The celebrated Mr. JOHN BERNOUILLI calculates the density of the air contained in a solid state in gunpowder to be $\frac{1}{1000}$ of what this fluid is when it constitutes a part of our atmosphere. But he does not consider this air as existing in all the component ingredients of the gunpowder, but chiefly in the nitre: and Count SALUCE supposes, that that part of the gunpowder which contains this air constitutes a considerable part of its bulk (though somewhat less than the half). Let us now suppose, that part of the gunpowder which contains this air to be not much less than the half of the whole mass (for it would be difficult to demonstrate accurately to what proportion of the whole mass this part amounts in reality). On this supposition we shall find, that the whole mass of gunpowder contains a quantity of air in a solid state which is reduced in bulk to near $\frac{1}{500}$, or, in other words, that one square inch of gunpowder contains near 500 square inches of air; which being heated in the moment of inflammation will expand to four times its diameter; so that according to this calculation gunpowder must expand in the moment of explosion to near 2000 times its own bulk.

It seems very probable, that this calculation of Mr. BERNOUILLI is much nearer the truth than that of

Mr. ROBINS and Count SALUCE; but yet the evaluation of the two last mentioned writers, though short of one half, proves in reality Mr. BERNOUILLI's calculations to be as just as can be expected, when it is considered, that this evaluation was made before the new discoveries upon the nature of nitre and charcoal. But this assertion will be better understood when I have explained the nature of gunpowder somewhat fuller.

If we continue to say, as we have hitherto done, that the charcoal taking fire decomposes the nitre, and extricates from it that amazing quantity of elastic fluid which was shut up within its substance, we only say what we see in reality is the consequence of setting fire to this ingredient. But this explanation does not convey a clear idea of the manner in which the extrication is carried on; nor of the reason why one single spark of fire, thrown into an immense heap of gunpowder, should almost in an instant spread the conflagration through the whole mass. Neither does it explain clearly, why nitre and charcoal (which separately yield no flame at all, though ever so much heated) when combined and intimately mixed together, explode with as loud a report as a large ordnance piece, surpassing even in loudness thunder-claps; nor why this forcible explosion is accompanied by a most brilliant flame.

Nitre

Nitre is composed of two different ingredients, *viz.* an acid, called from its peculiar nature the *nitrous acid*, and the vegetable alkali. Neither of these two ingredients are capable of inflammation; nay, they even extinguish actual fire. When they are both combined and constitute the neutral salt we speak of, they have not, even by their coalition in one body, acquired an inflammable quality, for nitre may be made red-hot in a crucible without shewing the least appearance of inflammation, not even when a red-hot stone or piece of iron is thrown into it. But if any common combustible substance, as wood, charcoal, or such like, is thrown into the melted nitre, a flame issues with a kind of explosion, though only at the very place where the two substances come into contact. The same flame and explosion is observed when cold nitre is thrown upon a combustible body, in a state of real ignition, on a piece of red-hot charcoal for instance.

The true reason of this wonderful phenomenon has not been considered hitherto with that degree of attention it deserves, and could not have occurred to any body before our modern philosophers had discovered the nature of various kinds of air, and the manner of extracting them from bodies.

Inflam-

Inflammable air, the *gas flammeum* of VAN HELMONT, was considered as an aerial fluid, susceptible of inflammation by itself.

But we now know, that inflammable gas concentrated will not burn at all; but on the contrary extinguishes flame. Mr. CAVENDISH was the first who set this matter in a proper light. He discovered, by experiments, that a mixture of a small quantity of common air with a great proportion of inflammable air, as, for instance, two parts of common air with eight parts of inflammable air, caught fire without noise, and consumed gradually; but that three parts of inflammable air and seven parts of respirable air exploded with a very loud sound.

It was Dr. PRIESTLEY's important discovery which suggested to me the theory I intend to lay before the Royal Society.

This acute philosopher found, that, if instead of common air, dephlogisticated air is mixed with a due proportion of inflammable air, the explosion is considerably louder.

The principal ingredients of gunpowder, and those to which it owes its force, are nitre and charcoal; for these two ingredients, well mixed together, constitute gunpowder at least equal if not superior in strength to common gunpowder (as I found by experience, and may be

feen in the Memoire of Count SALUCE, inserted in the *Melanges de Philosophie et de Mathematiques de l'Acad. Royale de Turin*). The sulphur seems to serve only for the purpose of setting fire to the mass with a less degree of heat.

Nitre yields by heat a surprizing quantity of pure dephlogistified air. Charcoal yields by heat a considerable quantity of inflammable air. The fire employed to inflame the gunpowder extricates these two airs, and sets fire to them at the same instant of their extrication. Thus the difference between the inflammation of gunpowder and that of a mixture of inflammable air with dephlogistified air in an ordinary air pistol (as these last are now contrived for a philosophical amusement) seems to be, that the compound of the two airs in the air pistol takes fire, when already extricated and existing in a space without compression or condensation; that is to say, when they are in no condition of exerting a much greater elasticity than what they acquired by the heat generated in the moment of their explosion; which heat can only expand them to four times their former bulk, according to Mr. ROBINS: whereas in gunpowder the two airs, existing in a solid state before their extrication, and occupying, according to Mr. ROBINS, about $\frac{1}{250}$ of the space they take up after they are set loose, but most probably

bably even less than $\frac{1}{300}$ (as will be seen by and by), are extricated all at once, when confined (as in fire arms) in a space $\frac{1}{250}$ or rather $\frac{1}{300}$ times less than they can occupy when reduced to the temperature of the common atmosphere, and of consequence 2000 less than they can occupy when heated in the moment of inflammation; so that the difference of the explosive force in the inflammation of the two compounds can be no less than as 4 is to 2000.

It must be here remembered, that air being a very compressible body, a moderate resistance acting against its rarefaction easily overcomes the force of its expansion, when this expansion or rarefaction does not amount to more than four times its bulk (that such a power ought not to be very great, we know by the force employed in ordinary wind guns and condensing machines) whereas no condensing machine has yet been contrived by which air could be condensed to any thing approaching the state of condensation of this fluid as it exists in the substance of nitre.

It might be here objected, that air compressed to one tenth in a wind gun possesses a power not much short of gunpowder, though only $\frac{1}{18}$ or $\frac{1}{20}$ of it is let loose at a time; and that thus, inflammable air, though expanded only four times in the moment of inflammation, may exert a force approaching that of the wind gun, the whole

mass of the charge being employed in one and the same explosion. This comparison is very inadequate; for in the case of a wind gun the air compressed to $\frac{1}{10}$ is ready to exert all the force of elasticity existing in the whole mass, and may therefore be compared to a strong spring forcibly bent. But the inflammable air is far from exerting the force of expansion and elasticity through its whole mass at the same instant: for the inflammation is propagated through it successively, beginning where the electrical spark kindles it, and reaching gradually farther till the whole is consumed. Now as I have demonstrated, that inflammable air is reduced to more than half its bulk by inflammation, it must follow, that that portion of it which is consumed the first by the inflammation, leaving more room by its diminution, diminishes in proportion the propelling powers of what remains still to be inflamed.

The very great difference between the explosive force of the two compounds is illustrated by what happens after their inflammation. The compound of inflammable with common or dephlogisticated air, is very much reduced in bulk after inflammation. I found this by the following experiment: I fired a brass inflammable air pistol (made by Mr. NAIRNE according to my directions) which had a piston in the cylinder, by which a proper
quantity

quantity of respirable and inflammable air was drawn in. I had rammed into the barrel, adapted to it, a leaden bullet wrapped up in a piece of leather so strongly that I did not expect the resistance could be overcome by the explosion. I fired it by an electrical spark; the inflammation took place, the pistol grew hot, the ball was not propelled, and the piston was driven more than half way down the cylinder by the pressure of the atmosphere acting upon it when the explosive air was consumed by the inflammation.

The case is quite different in the firing of gunpowder, as there remains after its inflammation a mass of air which occupies about 250 times the former bulk, according to Mr. ROBINS.

As, in the foregoing experiment, the compound of inflammable and common air was reduced above the half of its former bulk, it seems more than probable, that the quantity of dephlogisticated and inflammable air extricated in the firing of gunpowder must also undergo a similar diminution by its inflammation; so, that when there remains a mass of air, 250 times the bulk of the gunpowder, the quantity of air extricated from the powder must have been in reality not less than 500 times the bulk of the powder, which agrees nearly with the calculation of Mr. JOHN BERNOULLI. Let us now

see

see how far this computation agrees with the analysis of gunpowder. Abbé FONTANA, so advantageously known by his important discoveries in natural philosophy, more especially by those he has made on the various kinds of air, favoured me with the following result of his experiments. An ounce of nitre, exposed to a great degree of heat for the purpose of extracting its air in the usual way, yielded about 800 cubic inches of dephlogisticated air. An ounce of charcoal, treated in the same way, gave about 150 cubic inches of air, partly fixed, partly inflammable, mixed with some common air.

Let us now calculate (without, however, being too scrupulous about the accuracy of the result) what quantity of elastic permanent fluid a cubic inch of solid gunpowder will give in the moment of deflagration: a cubic inch of solid gunpowder contains in weight 442 grains (which is 38 grains short of an ounce Troy weight) of which $331\frac{1}{2}$ grains is nitre, $55\frac{1}{4}$ charcoal, and as much sulphur (supposing the proportion of the ingredients of the powder to be six parts of nitre to one of charcoal and one of sulphur); $331\frac{1}{2}$ grains of nitre will give about 552 cubic inches of dephlogisticated air; $55\frac{1}{4}$ grains of charcoal will produce about 17 cubic inches of air, chiefly inflammable, according to the calculation of Abbé FONTANA.

By

By this calculation, which will, perhaps, be found more accurate than the former, one cubic inch of solid gunpowder will yield above 569 cubic inches of permanent elastic fluid: I say, above 569 cubic inches, for I do not put into the account the elastic fluid which is generated by the sulphur, nor that which charcoal, consumed by the inflammation of the gunpowder, yields above the quantity mentioned, which it gives when heated in a glass vessel, by which it is by no means consumed, an ounce losing by this operation only 60 grains of its weight.

As this elastic fluid will increase to four times its bulk, it follows, that one cubic inch of solid gunpowder will extricate in the moment of explosion above 2276 cubic inches of elastic air. Which computation is not far from the result of my former calculation, and that of Mr. BERNOULLI.

An accurate calculation of the expansion of gunpowder would be a very difficult undertaking. The expansion of the moisture always contained in gunpowder, however dry, may also contribute its share towards the amazing powers of this ingredient. Nitre contains from its nature a great share of water, which is necessary for the crystallization of it, and charcoal is always found to contain it. We know,

that very hot vapour is capable of occupying almost 2000 times the space it did in the state of cold water.

The generation of dephlogisticated and inflammable air by the inflammation of gunpowder is the reason why this ingredient is almost the only one known, which does not want a free access of common air to be consumed by fire; and therefore it may be said to feed, as it were, upon its own air.

This theory of gunpowder induces me to venture a new one of the *pulvis fulminans*, which consists of three parts of nitre, of two of fixed alkaline salt, and of one of sulphur. This powder much surpasses the force of gunpowder in exploding, with a very loud report, in the open air when it is heated to a certain degree. It is commonly said, that in the heating of this powder the sulphur joins with the alkaline salt and constitutes an *hepar sulphuris*, which rising up in bubbles confines the air contained in them, which air at last becomes so powerfully expanded that it overcomes and breaks through the resistance of the coercive bubbles of the *hepar sulphuris*, with all the force of its elasticity; which sudden emission must naturally occasion a proportional sound. But I think, that the nitre contained in this powder, being heated, yields its dephlogisticated air when the melting sulphur yields inflammable air; at the same time the sulphur constitutes
with

with the alkaline salt, an *hepar sulphuris*, which rising in tough bubbles confines this explosive air generated. At length, however, the increasing heat, which sets fire to the sulphur, sets this explosive air on fire also; which then following its own nature explodes with so much the more force from its having been entangled and confined within the bubbles of the *hepar sulphuris*.

After what has already been said, it will not be difficult to explain, why a single spark of fire propagates the combustion with great rapidity through the whole mass of gunpowder, however great. If we put a single grain of gunpowder upon a red-hot iron, we see the particles of red-hot charcoal projected with great rapidity in every direction by the forcible explosion of the two airs extricated in the manner before explained. Thus, if one or more grains, among a heap of others, are set fire to, the particles of red-hot charcoal being driven with great violence against the surrounding grains communicate their heat to all the particles of charcoal they hit, which particles, by heating the particles of nitre in close contact with them, extricate their dephlogisticated air at the same time that the charcoal yields its inflammable air; in consequence of which a more powerful explosion happens. This secondary explosion projects with a much greater force the particles of charcoal surrounded by the explosive

flame of the two airs; and thus the conflagration spreads with a very great velocity through the whole mass, though always by succession. The quickness of this propagation of fire depends in a great measure upon the intervals or interstices which remain among the grains of gunpowder, through which the particles of heated charcoal are driven in every direction, together with the flame of the two airs. Hence gunpowder reduced into impalpable powder, and rammed into a squib, does not inflame with an explosion, but burns slowly farther and farther till the combustion reaches the extremity of the squib, where it meets a mass of gunpowder in grains, when immediately a loud explosion issues, by which the squib is shattered into rags. Hence the size of the grains of gunpowder must be proportionate to the size of the fire arms to which it is destined, the greatest fire arms requiring in general grains of the largest size.

If this wonderful and awful ingredient had not been discovered by accident, could the secret have escaped a long while the penetration of our modern philosophers, who have found out the way of combining the air of the two constituents after they had extricated them, without any regard to the known properties of gunpowder? Nothing more was to be done than combining the two sub-

stances instead of combining the two airs first separated from them.

A P P E N D I X.

IN the foregoing paper I attempted to give a comparative view of the explosive force of gunpowder and inflammable explosive air, which latter I had found to be so far short of the explosive force of gunpowder as not to conceive any well grounded hope that it could ever become a substitute to this ingredient.

At that time I had not yet tried the effect of very pure dephlogisticated air combined with that inflammable air, into which I had found that vitriolic æther is changed in an instant.

I must acknowledge, that I had but small expectations from the force of these two airs combined; for as I had always observed, that æther air combined with common air is less brisk in taking fire, and less powerful in exploding, than inflammable air extracted from the vitriolic or marine acid, I thought that the same æther air combined with very pure dephlogisticated air would also

be less powerful than common inflammable air from metals. But how far experience contradicted this theoretical analogy will be seen in the following lines.

Abbé FONTANA was so good as to assist me in this pursuit. Having produced a good quantity of pure dephlogisticated air from red precipitate by heat, we first filled a strong two-ounce phial (the orifice of which was so wide that it could scarce be covered with the thumb, so that the bottle was almost cylindrical) with this air, in the usual manner, by filling it first with water, inverting it, and letting the air rise in it; which being done, we dropped one drop of æther (in which a small quantity of camphire was dissolved) into it, and shut it immediately with the thumb. After having given it some concussions, the orifice was applied to the flame of a candle, by withdrawing the thumb when the orifice was close to the flame: the air instantly took fire, and exploded with such a strong report, that, if the phial had not been very stout, it would most probably have been shattered into pieces, notwithstanding its wide orifice. We repeated the same experiment with the same success.

I was the more astonished at the uncommon loud report (considering the wide orifice of the phial), because, having often tried æther air in the same way with common air, I never found it explode with any

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considerable degree of force; and therefore I found it necessary, in order to procure a loud report, to kindle it by an electrical spark directed through the pistol, when its orifice was shut up by a cork, the resistance of which was the chief cause of the report.

This wonderful effect in an open vessel could not fail of giving me a good expectation of a very powerful effect, if this compound air was shut up in an air pistol by a cork squeezed into its orifice. As it had been now kindled twice by the flame of a candle, I wanted to kindle it by the same means in an air pistol; for this purpose we drilled a small hole in the side of the pistol, which was made of tin, and contained about nine cubic inches of space. We filled it with dephlogisticated air in the same manner as we had filled the phial by means of water; and after having poured into it one drop of æther by means of a glass tube (in the manner above described), we shut the orifice by thrusting a cork into it, and kept a finger applied to the touch-hole which was drilled in the side of the pistol. To avoid accidents if the pistol should burst, we thought it prudent to squeeze the cork very gently into the orifice, so that the resistance should be very moderate. Abbé FONTANA wrapped a towel round the pistol for security's sake, leaving only the touch-hole uncovered; which being brought near the flame
of

of a wax taper, the air instantly took fire, and exploded with such a strong report, that his hearing, as well as mine, was much hurt by it. The cork, which was a very sound one, flew to pieces against the wall; and the Abbé felt such a considerable shock in his hands, that he did not think it safe to repeat the experiment, unless a stronger pistol could be procured.

Encouraged by such uncommon and unexpected effects, I went immediately to Mr. NAIRNE to inquire, whether he still had in his possession a strong brass air pistol, which he had made last summer according to my direction? I was lucky enough to find it; nothing was to be done to it but to drill a touch-hole in the left side of it, in order to kindle it by a flame if required. This touch-hole was to be shut up by a brass male screw fitted exactly to it, when the pistol was intended to be fired by an electrical spark.

The air box of this pistol was a cylinder four inches long and two inches in diameter. The fore part of the air box to which the pistol barrel fitted to receive a leaden ball or a cork, was fixed, had a broad shoulder, which was fastened to the body of the air box by six strong brass screws, which never had been loosened by former explosions. A leaden bullet, wrapped up in leather, was forcibly rammed into the pistol barrel as far as the screw, which
joins

joins the barrel with the air box (as may be seen in the figure). The pistol was filled with pure dephlogisticated air (which was drawn-in by the piston from an elastic gum bottle), and one drop of æther being poured into it, the air within was kindled by an electrical spark directed through it. The air took fire: the explosion was as loud as that of a common musket, and the force so great, that the whole fore part of the air box with the pistol barrel flew off, all the six screws were broke, and the strong and tough metal of which they were made was rent. Three strong brass screws, by which the bottom of the air box was fixed to the wooden handle, were loosened, and the whole frame of the pistol was out of order. The substance of the air barrel, where it was tore, was of the thickness of about a half crown piece.

Being now convinced, that though inflammable air from metals with dephlogisticated or common air, is far inferior to the force of gunpowder, the explosive force of the compound of dephlogisticated and æther air approaches it much nearer, I thought it worth while to fit the pistol up in such a manner as to be out of all danger of bursting. For this purpose I desired Mr. NAIRNE to adapt, and solder to the fore part of the air box, a hollow cone of brass, the extremity of which should terminate in the gun barrel.

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As the piston could not reach to the extremity of this conical hollow (which consequently must be always filled with common air), I desired him to fix to the piston an ivory cone, through which the two wires would pass to meet one another at the surface of the cone, leaving an interstice between them of about one line, through which the electrical spark should leap and set fire to the air. This ivory cone shutting up exactly the whole cavity of the air box, no air could come into it but what was drawn in by the piston.

The pistol thus fitted up answered tolerably well. The figure joined to it will serve to give a better idea of the whole contrivance than could be well explained by words. The scale is in the proportion of one third of the real size.

The cone, instead of ivory, may be made of solid glass, which is a better non-conductor than ivory. The canals in the ivory, through which the two wires pass, may be made wide enough to contain a glass tube, through which the wires pass; or to be filled with a non-conducting cement, as sealing wax, for the same purpose. The cone may even be made of brass, provided two glass tubes are lodged in it, to give a passage to the two wires.

I kindle this pistol sometimes by putting in the touch-hole a little bit of a cotton thread soaked in moist gunpowder

powder and dried afterwards; or a bit of those paper matches which the Chinese put into those little squibs, which go by the name of *India crackers*. I sometimes kindle it by holding the flame of a candle or a burning paper to the touch-hole. In this case it is to be observed, that the touch-hole must be kept upwards, if the pistol is loaded with inflammable air from metals, because this air being lighter than common air, will rise out of the hole and meet the flame. The contrary must be done when æther air is employed, it being heavier than common air, and thus disposed to descend and fall upon the flame kept under it.

To fill this pistol with any air, I commonly first fill an elastic gum bottle with it, the orifice of which is just big enough to receive that part of the gun barrel which is fixed to the air box: thus, by squeezing between my feet the elastic gum bottle, I draw in at the same time the air by drawing up the piston. A bladder is also very fit for this purpose, and has the advantage above an elastic gum bottle in not requiring to be squeezed to draw the air out of it.

Inflammable air from metals will rise in the pistol of itself, when its orifice is kept upon the bottle containing it.

If the pistol is destined to be always kindled by the flame of a candle or a match, as I have described, it would be better to have no piston to it, as it may then be filled by the means of water, and the explosive force will be so much the greater, as some of the flame makes easily its way over the leather of the piston, and rushes out backward, which, I find, is often the case, if the bullet is rammed in the barrel somewhat too tightly.

It would, perhaps, not be an easy undertaking to give a satisfactory reason, why a drop of æther communicates to dephlogisticated air a much stronger explosive force than common inflammable air from metals. May it not be said, that common inflammable air from metals, having only about one fifth of the specific gravity of the dephlogisticated air, the two fluids do not penetrate one another so readily and so intimately as the compound of dephlogisticated and æther air, which are both nearly of the same specific gravity, each being somewhat heavier than common air? for it seems not improbable, that the swiftness with which the flame is propagated through the mass of this compound air, depends partly on the intimate mixture of the phlogiston with the dephlogisticated air. Might not this phenomenon be ascribed to the greater bulk of inflammable air from metals compared with the small compass which one single drop

drop of æther occupies, which last ingredient, when pure, seems to be an essence of the inflammable principle of the spirit of wine, a pure phlogiston concentrated in the form of a liquid? Indeed the inflammable air from metals seems to be rather a compound of phlogiston and some kind of elastic permanent fluid than a pure inflammable fluid; for this air, after having lost all its inflammability, by being kept a long while upon water, occupies still a considerable space, and is then become phlogisticated air; that is to say, such an air as is not to be diminished by nitrous air, or to be inflamed.

Though I have no reason to alter my former assertion, that the force of gunpowder is proportionable to the sudden extrication of a great quantity of the elastic fluid generated in the moment of conflagration, and the expansion of this fluid by heat, communicated to it in the same moment of its extrication; and that the force of inflammable explosive air can only be proportionable to the sudden expansion by heat in the moment of the inflammation (for no new extrication here takes place); yet I did not consider enough in the account the suddenness of this expansion, which may make a considerable difference in the force of the explosion. And indeed the abovementioned experiments seem to demonstrate, that the inflammation of the compound of pure dephlo-

gified and æther air spreads with such a velocity through the whole mass as to be almost instantaneous.

It is well known, that mechanical power chiefly depends upon the velocity with which a body is endowed in the instant of exerting it; or that the *momentum*, or force of a body, must be computed by multiplying the quantity of matter into the velocity with which it moves. Thus, if this new compound of dephlogified and æther air expands with ten times greater velocity than any other inflammable explosive air, its force will be about ten times greater.

As it seems to be probable, from what is already said that this compound of explosive air may be put to more uses than that of an amusing experiment, I think it worth while for men engaged in this branch of natural philosophy to look out for a method of producing at pleasure any quantity of dephlogified air required. Considering the rapid progress which is daily made on the important subject of air, I cannot but flatter myself, that this great discovery is not far off. The benefit which would arise from such a discovery for animal life must encourage every philosopher to pursue this object. Indeed, if we consider that nitre contains this wonderful aerial fluid in a most concentrated state, and that the nitrous acid seems to be nothing else but this beneficial
fluid

fluid combined with phlogiston, which seems to be imbibed by the vegetable alkali, when the acid is expelled by heat in the form of this air; that this beneficial aerial fluid exists also, in a most concentrated state, in bodies almost every where to be found, as are calces of metal, principally that of iron; that common water contains it in great abundance, so that the light and warmth of the sun extracts it to one fifteenth of the bulk of the water, as Dr. PRIESTLEY found, that even the mass of our atmosphere is nothing else but this very air foiled with impurities. If we consider, I say, all this, is it not reasonable to hope, that we are near the important instant when this salubrious aerial fluid will be procured for many useful purposes in a sufficient quantity, either by the discovery of a ready way to let loose this air from the bodies in which it is as it were imprisoned, or by filtering or purifying common air from its impurities?

EXPLANATION OF THE FIGURE.

A *a* the pistol barrel.

B the large cylinder or air box.

b the place where the pistol barrel unscrews from the air box.

c the pistol handle.

D the

- D** the handle fixed to the piston at *bb*, which is square to prevent the pistons turning round.
- E** the hole in the side of the air box.
- e** the screw to stop the said hole.
- F** a piece of brass with a female screw, which was fixed with three strong screws to the wooden handle.
- f** a screw at the end of the air box which screwed into the piece **F**.
- G** a piece of ivory fixed to the piston.
- g** the piston, with the piece of conical ivory fixed to it.
- L** the termination of the ivory cone which filled up the small end of the air box.
- M** the perforation in the wooden handle, through which the brass handle **D** passes.
- N** a brass ball at the end of a wire, which passes down the canal **R** in the ivory cone.
- O** another piece of wire passing down the other canal, canals are filled with non-conducting substance.
- P** an interstice between the two wires of about one line, through which the electrical spark, when given on the ball **N**, passes and sets fire to the inflammable air in the air box.



